APPENDIX G

SEISMICITY

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The distribution, recurrence, and intensity of earthquakes over a period of time describe the seismicity of a region. Earthquakes occur as the result of the release of stored energy that can cause the rupture of brittle earth materials within and at the surface of the earth. The rupture surface along which the earth is displaced, one side relative to the other, is called a fault. Surface expression of this displacement is referred to as a fault trace or fault line. The recognition of enduring expression of ground surface rupture is the primary source of evidence used by geologists to identify the location of faults. Many historic, damaging earthquakes have not produced ground surface rupture.

The occurrence of an earthquake produces seismic waves that emanate in all directions from the origin of the earthquake, or epicenter. The seismic waves cause groundshaking which is typically strongest at the epicenter and diminishes (attenuates) as the waves move through the earth away from the source of the quake. The severity of groundshaking at any particular point is referred to as intensity and is a subjective measure of the effects of groundshaking on people, structures, and earth materials. Intensity is typically expressed by the Modified Mercalli Scale (Table G-1). The effects of ground shaking on structures depends on the design, quality of construction, and foundation materials.

Seismic waves and associated ground motion generated by earthquakes can also be detected and measured by instruments called seismographs and accelerometers. The measurement of the energy released at the point of origin, or epicenter, of an earthquake is referred to as the magnitude, which is generally expressed by the Richter Magnitude Scale. The Richter Scale is logarithmic; each successively higher Richter Magnitude reflects an increase of about 31.5 times the amount of energy released by an earthquake. As such, the Richter magnitude is a specific measurement of the power of an earthquake as it occurs.

Active and Potentially Active Geologic Faults in the Project Vicinity

The following discussion provides additional information about seismic activity and the potential for future earthquakes in the project vicinity and supplements the discussion found in Section 4.6, Geology, Soils, and Seismicity. The reader may wish to refer to Table 4.6-1 and Figure 4.6-4 in the main text for graphic and tabular presentation of data.

Active Faults

San Andreas Fault Zone

The San Andreas Fault Zone, a complex right-lateral strike slip fault zone, extends over 600 miles from the Gulf of California in Mexico to Cape Mendocino in northern California. The SAFZ has been divided into discrete segments on the basis of historic seismicity and evidence of ground surface rupture (USGS, 1990). Segments of the SAFZ capable of generating earthquakes which could affect the project site include the North Coast segment, the San Francisco Peninsula segment, and the southern Santa Cruz Mountains segment. The SAFZ is located approximately 46 miles west of the project site.

TABLE G-1
MODIFIED MERCALLI SCALE[1]

	Intensity	Effects	v,[2] cm/s	g[3]
M[4]	I.	Not felt. Marginal and long-period effects of large earthquakes.		
3	II.	Felt by persons at rest, on upper floors, or favorably placed.		
	III.	Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.		0.0035-0.007
4	IV.	Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of IV wooden walls and frame creak.		0.007-0.015
	V.	Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate.	1-3	0.015-0.035
5	VI.	Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken (visibly, or heard to rustle - CFR).	3-7	0.035-0.07
6	VII.	Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments - CFR). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged.	7-20	0.07-0.15
	VIII.	Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.	20-60	0.15-0.35
7	IX.	General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. (General damage to foundations - CFR.) Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluviated areas sand and mud ejected, earthquake foundations, sand craters.	60-200	0.35-0.7
8	X.	Most masonry and frame structures destroyed with their foundations. some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.	200-500	0.7-1.2
	XI.	Rails bent greatly. Underground pipelines completely out of service.		>1.2
	XII.	Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.		

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[1] From Richter (1958).
[2] Average peak ground velocity, cm/s.
[3] Average peak acceleration (away from source).
[4] Richter magnitude correlation.

Notes: Masonry A, B, C, D. To avoid ambiguity of language, the quality of masonry, brick or otherwise, is specified by the following lettering (which has no connection with the conventional Class A, B, C construction).

- *Masonry A:* A Good workmanship, mortar, and design, reinforced, especially laterally, and bound together by using steel, concrete, etc; designed to resist lateral forces.
- *Masonry B:* Good workmanship and mortar, reinforced, but not designed to resist lateral forces.
- *Masonry C:* Ordinary workmanship and mortar; no extreme weaknesses such as non-tied-in corners, but masonry is neither reinforced nor designed against horizontal forces.
- *Masonry D:* Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.

The 1906 San Francisco earthquake, a magnitude[1] 8.3 event, resulted in rupture of all of these segments and produced moderately intense ground shaking (Mercalli equivalent of VI to VII) in the western San Joaquin Valley (California State Earthquake Investigation Commission, 1908-10). The USGS (1990) estimates the probability of an MCE of magnitude 8 on the North Coast segment of the fault within the next 30 years to be two percent. The magnitude 7.1 Loma Prieta earthquake in 1989, which occurred along the southern Santa Cruz Mountain segment, produced Modified Mercalli Intensity (MMI) VI in the area of the project site (USGS, 1989). The probability of a similar earthquake on this segment in the next 30 years is estimated to be less than one percent (USGS, 1990). The San Francisco Segment of the SAFZ is expected to produce an MCE of magnitude 7 with a probability of 37 percent within the next 30 years (USGS, 1990).

Considering the distance of the project site from the SAFZ, the estimated peak ground acceleration produced at the site during the expected magnitude 8 MCE would be 0.18g. The expected maximum MMI associated with this event would be VIII.

Hayward Fault Zone

The Hayward Fault Zone (HFZ) is a right-lateral strike slip fault zone within the SAFZ which extends approximately 60 miles from San Jose northwestward to Point Pinole near Richmond. The fault zone has been divided into a northern and southern segment on the basis of seismicity and fault rupture history (USGS, 1990). The Rodgers Creek Fault Zone, extending from San Pablo Bay to north of Santa Rosa, is considered to be a possible extension of the HFZ. Major earthquakes in 1836 and 1868, both estimated to be magnitude 7 events, occurred along the HFZ. An earthquake of similar magnitude on either segment of the zone is considered to have a probability of 39 percent in the next 30 years. The probability of a magnitude 7 event on the Rodgers Creek Fault Zone is estimated to be 33 percent over the same period (USGS, 1990).

The HFZ is located approximately 27 miles west of the project site. The estimated peak ground acceleration at the project site an MCE on the HFZ would be approximately 0.16g. A maximum MMI of VII to VIII would be expected at the project site during such an event.

Calaveras Fault Zone

The Calaveras Fault Zone (CFZ) is located east of the HFZ at a distance of approximately 21 miles west of the project site. This right-lateral strike slip system extends approximately 100 miles northwestward from Hollister as a complex zone of faulting. Recorded seismicity in the vicinity of the fault includes over 50 earthquakes of MMI of V or greater in the period 1930 to 1972 (Armstrong et al., 1980) and Richter magnitude 6 events in 1979 and 1984. The maximum credible earthquake for this fault zone is estimated to be moment magnitude 6.3 to 7.5 (Wesnousky, 1986; Mualchin and Jones, 1992). Using the higher estimate for the MCE, the expected peak acceleration at the site would be 0.19g with an associated MMI of VIII.

The project is located near the Coast Range-Sierran Block Boundary (CR-SBB) Zone. The CR-SBB Zone is currently recognized as a potential seismic source, capable of generating moderate earthquakes within the study area (Wong, et al., 1988; Mualchin and Jones, 1992). Recent evaluations of the CR-SBB indicate that tectonic compression occurs across the boundary as the Coast Range Block is tectonically pushed against the Sierran Block. The result of this active compression is the development of folds and thrust faults within the CR-SBB zone. The

faults associated with this zone do not typically propagate to the surface and are, therefore, called "blind thrusts." Because the faults are not expressed at the surface, identification of the locations of the faults cannot, typically, be determined on the basis of geomorphic evidence commonly associated with recent fault rupture. Evidence of folding and uplift of Quaternary deposits within the CR-SBB Zone have been identified by regional geomorphic analysis conducted in the vicinity of the site (Sowers, et al., 1992). Fold in deep sedimentary rocks identified (Bartow, 1991) in the area east of the project site may also be related to compression within the CR-SBB Zone.

The CR-SBB Zone is considered capable of generating moderate to large earthquakes which could produce strong groundshaking throughout the region, including the project site. The 1983 Coalinga earthquake (Magnitude 6.7) is a recent example of earthquake which occurred on a blind thrust within the CR-SBB zone. The historic 1892 Vacaville-Winters earthquakes (estimated Magnitude 6+) are generally regarded as having also occurred within the CR-SBB Zone (Unruh and Moore, 1992). The proximity of the CR-SBB Zone to the project site and the expected large MCE (magnitude 6.5 to 7) within the zone indicate that this seismic source could produce strong groundshaking (MMI IX) at the project site.

Greenville Fault Zone

The Greenville Fault Zone (GFZ) has been interpreted as being the easternmost of the major branches of the SAFZ. The GFZ is a 90-mile long system of northwest trending fault segments which include the Clayton, Marsh Creek, Greenville, and Arroyo Mocho segments. Historic seismicity within the GFZ includes a swarm of earthquakes in January 1980 which included Richter magnitude 5.5 and 5.8 events; these events generated surface fault rupture in the Livermore area. The relationship of the GFZ to several faults considered to be potentially active, including the Tesla, Corral Hollow, Carnegie, and Patterson Pass Faults, is not well studied. Recent investigations in the southwestern corner of San Joaquin County have uncovered evidence of Holocene activity on the Corral Hollow fault (Carpenter, 1991).

Estimates of the MCE for the Greenville Fault Zone range from moment magnitude 6.8 to 7.25 (Wesnousky, 1986; Mualchin and Jones, 1992). The occurrence of a magnitude 7 earthquake on this fault, located approximately 8 miles west of the project site, would generate ground acceleration of approximately 0.50g. The associated MMI could be as high as IX.

Green Valley-Concord Fault Zone

The Green Valley and Concord Faults are the primary faults of a two-mile wide complex fault zone located approximately 27 miles west of the project site. The fault zone extends from east of Benicia to east of Walnut Creek. Active seismicity and fault creep (noted in Concord) have been attributed to the zone (Ellsworth, et al., 1982). Historic seismicity in the fault zone includes a Richter magnitude 5.4 event in 1955. A swarm of earthquakes in 1989, centered near Alamo, appears to have occurred on a fault located between the Concord and Calaveras faults, suggesting a link between the two major fault zones (Oppenheimer, 1991). The estimated MCE for the Green Valley and Concord faults is estimated to be moment magnitude 7. The effects of the MCE on this fault would be similar to those described for the Hayward Fault.

~~*Antioch Fault*~~

~~The Antioch Fault is located near Antioch approximately 16 miles northwest of the project site. Numerous small to moderate earthquakes, including nine earthquakes with Richter magnitudes in the 2.5 to 5.0 range, were recorded in the vicinity of the fault from 1962 to 1971. The fault trends northwest, but its total length is unknown. The MCE for this fault is estimated to be moment magnitude 6.75 (Wesnousky, 1990).~~

Ortigalita Fault Zone

The Ortigalita Fault Zone is a northwest-trending zone along the eastern edge of the Diablo Range. Evidence of Holocene movement (Anderson, et al., 1982) and active seismicity have been identified along some segments of the fault zone. A Richter magnitude 5 earthquake in 1926, a magnitude 3.7 in 1981, and smaller earthquakes monitored from 1969 to 1980 occurred in the vicinity of this fault zone.

The Ortigalita fault zone is considered capable of generating earthquakes of Richter magnitude 6.5 to 6.75 (Anderson, et al., 1982). The recurrence of earthquakes resulting in surface rupture is on the order of 5,000 to 10,000 years for the entire fault zone. The O'Neill Fault system, the northernmost segment of which is about 30 miles southeast of Stockton, is considered to be related to the Ortigalita Fault (Lettis, 1982). Sufficient evidence of recent fault rupture on this segment has not been identified to warrant zoning under the Alquist-Priolo Act (Hart, 1990), and this fault is considered to be potentially active.

Potentially Active Faults

Antioch Fault

The Antioch Fault is located near Antioch approximately 16 miles northwest of the project site. Numerous small to moderate earthquakes, including nine earthquakes with Richter magnitudes in the 2.5 to 5.0 range, were recorded in the vicinity of the fault from 1962 to 1971. The fault trends northwest, but its total length is unknown. The MCE for this fault is estimated to be moment magnitude 6.75 (Wesnousky, 1990).

San Joaquin Fault Zone

The San Joaquin Fault Zone is located along the western edge of the San Joaquin Valley extending from north of Tracy southeast to south of Los Banos. The San Joaquin Fault system has not been extensively studied. The fault is considered capable of generating an earthquake of magnitude 6.6 and evidence suggests a recurrence interval of about 1,000 years (Wesnousky, 1986). The mapped trace of the fault within San Joaquin county does not have sufficient evidence of surface rupture to be considered active within the guidelines of the Alquist-Priolo Act (Hart, 1990).

Midway Fault

The Midway Fault is a northwest-trending fault in the foothills of the Diablo Range. This fault is located approximately two miles west of the project site. Although the Midway Fault has been mapped as a poorly defined fault, only the northern portion of the fault is currently considered active as far south as southwestern San Joaquin County (Dibble, 1980). A maximum earthquake of moment magnitude 6.3 with a recurrence interval of about 2,600 years has been suggested for this fault (Wesnousky, 1986).

Midland Fault

The Midland Fault extends northwest from Brentwood in the Delta to east of Lake Berryessa in Yolo County for a length of approximately 62 miles. For most of its length, the fault is concealed by sediments.

The fault has been considered a possible seismic source for the 1892 Vacaville earthquakes (Richter magnitude 6.8). Recent studies (Bolt, 1985; Eaton, 1986) suggest that the seismic source for the earthquake was west of the Midland Fault, but do not preclude the possibility that the fault was the source of the 1892 earthquakes. The Midland Fault is therefore considered a potential source of earthquakes and an MCE of Richter magnitude 7.0 (Greensfelder, 1974) has been assigned to this fault.

Patterson Pass-Black Butte

The Patterson Pass Fault and Black Butte Fault are northwest-trending faults in the foothills of the Diablo Range in the southwestern corner of the county. The faults may be an extension of the Midway Fault. Geomorphic evidence suggests Quaternary activity on these faults, but there is insufficient evidence of Holocene activity for regulation under the Alquist-Priolo Act (Hart, 1990).

Tesla Fault

The Tesla Fault is a mapped fault in the southeastern portion of the Tracy Planning Area. The fault has been described as a northward extension of the Ortigalita Fault (Oakeshott, 1980). Little evidence exists of Holocene or Quaternary activity on this fault, although seismicity (including a Richter magnitude 4.6 earthquake in 1946) has been recognized in the vicinity of the fault (Bolt, 1985). The fault has been interpreted as being a remnant of an older, inactive fault system. Young active faults, such as the Greenville Fault, offset the Tesla Fault.

Endnote

1. Throughout this discussion earthquake magnitude has been reported according to magnitude scales used in the referenced document. Where possible, moment magnitude has been used. The USGS provides the following discussion of magnitude:

Magnitude. A number that characterizes the size of an ***earthquake***, usually based on measurement of the maximum **amplitude** recorded by a ***seismograph*** for earthquake waves of a particular ***frequency***. Scales most commonly used are (1) local magnitude (M_L, commonly referred to as "Richter magnitude"), (2) surface-wave magnitude (M_S), and (3) body-wave magnitude (m_b). None of these scales satisfactorily measures the largest possible ***earthquakes*** because each relates to only certain frequencies of **seismic waves** and because the spectrum of radiated seismic energy changes with the earthquake size. The recently devised moment magnitude (M) scale, based on the concept of seismic moment, is uniformly applicable to all sizes of earthquakes.

Body-wave magnitude (m_b): Measures the type of waves that pass through the interior - the body - of the planet and that have a period of between 1 to 10 seconds.

Local magnitude (M_L): A scale most accurately applied when dealing with California earthquakes. It is still quite useful today for describing smaller and more moderate earthquakes, but is not useful in larger earthquakes.

Surface-wave magnitude (M_S): Scale formulated to describe earthquakes at distant locations. The scale principally measures **surface waves** with a 20-second period, or a wavelength of approximately 37 miles.

Moment magnitude (M): This is today perhaps the most meaningful scale for large and great earthquakes, in that it measures total energy released. The measurement takes into account the surface area of the fault that moved to cause the earthquake, plus the average displacement of the fault plane, and the rigidity of the material of the fault. A seismic moment, M_o, is the result, and when that is combined with an energy-magnitude formula, the outcome is a common means of measuring the greatest earthquakes on the planet, such as in Alaska, 1964, and Chile, 1960. This scale was developed very recently, which is why great earthquakes, such as that in Alaska in 1964, which were once related in the M_S 8.5 range have been upgraded to an M rating in the low 9s.